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Disposition of Anthracene in the Water and Aufwuchs Matrices of a Large Outdoor Channel Microcosm: A Data Set for Mathematical Simulation Models

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DISPOSITION OF ANTHRACENE IN THE WATER AND AUFWUCHS MATRICES OF A LARGE OUTDOOR CHANNEL MICROCOSM: A DATA SET FOR MATHEMATICAL SIMULATION MODELS

by

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16. ABSTRACT

Large-scale, outdoor microcosms were used to study the fate of anthracene, a polycyclic aromatic hydrocarbon, in the aquatic environment. The study provides a data set for describing the disposition of anthracene in the water and aufwuchs of the microcosms for the purpose of comparison with existing laboratory information and as an aid in refining and validating EPA's Exposure Analysis Modeling System and other computer models. Such models are used to estimate the exposure, fate, and persistence of synthetic organic chemicals in natural waters using easily measured physical and chemical properties of the compounds and the ecosystems. The major loss of anthracene from the channel was due to photolysis, with some loss attributable to volatilization.

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FOREWORD

Environmental protection efforts are increasingly directed toward preventing adverse health and ecological effects associated with specific compounds of natural or human origin. As part of this laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Environmental Systems Branch studies complexes of environmental processes that control the transport, transformation, degradation, fate, and impact of pollutants or other materials in soil and water and develops models for assessing exposures to chemical contaminants.

Polycyclic aromatic hydrocarbons (PAH) have engendered considerable environmental interest because of their potential health hazard to humans. Assessment of risk associated with exposure to these compounds requires information on their transport and fate in water supplies. In the study reported here, the behavior of anthracene, a commercially important PAH produced in large quantities in the United States, was examined in large-scale complex microcosms. The research data will aid in the development and validation of aquatic exposure assessment models.

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ABSTRACT

With increasing numbers of synthetic organic chemicals being marketed each year there is a need to estimate the exposure, fate, and persistence of these compounds in aquatic ecosystems without implementing elaborate screening protocols for each chemical. Computer models, such as EXAMS, are being developed to predict this information by utilizing well known or easily measurable physical and chemical properties of the compound and relevant ecosystem transport characteristics. Large-scale complex microcosms can be important tools for providing the data sets necessary to evaluate and facilitate the development of predictive models. This experiment was conducted to provide a data base to compare model predictions generated by computer models, such as EXAMS.

Anthracene was introduced (~ 14.7 $\mu g \cdot \ell^{-1}$) into a biologically colonized channel microcosm for 36 days. Anthracene concentrations in the water showed significant diel variation. Maximum water concentrations were achieved and maintained during periods of darkness. However concentrations decreased significantly with distance downstream during daylight periods. The major loss of anthracene from the channel was due to photolysis, with some loss attributable to volatilization. Anthraquinone concentrations increased as anthracene concentrations decreased during daylight periods. However, anthraquinone did not account for all anthracene losses, suggesting that other photolytic degradation products may have been formed from anthraquinone. A mass balance accountability of anthracene was not possible since analysis for other breakdown products was not attempted. Greater than 60% of the nominal anthracene input to the channel was lost by nonadditive processes during periods of light.

Aufwuchs accumulated anthracene and achieved maximum concentrations within 4 days of initiation of input. Aufwuchs did not biodegrade anthracene and losses from the water due to aufwuchs uptake were small (~ 0.02% of total anthracene input). Anthracene concentrations in aufwuchs were similar throughout the length of the channel. Aufwuchs biomass decreased down the length of the channel, thus, anthracene concentrations, expressed on a surface area basis, also decreased with distance downstream. A bioconcentration factor (BCF) for aufwuchs was calculated using the anthracene concentrations measured for aufwuchs and the 24 hour weighted water concentrations. BCF were not significantly different with distance downstream or through time. The overall BCF for aufwuchs was 1260 $\pm$ 96 ($\bar{x}$ $\pm$ 95% CI, n = 45).

Upon termination of anthracene input, concentrations in water returned to background levels within 24 hours. Anthracene depuration from aufwuchs was rapid with concentrations returning to background levels within 72 hours.

This report was submitted in fulfillment of Interagency Agreement No. AD-89-F-1-703-1 by the Savannah River Ecology Laboratory under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 1981 to September 1982, and work was completed as of September 1982.

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SECTION 1

INTRODUCTION

Anthracene is a member of the class of organic chemicals known as polycyclic aromatic hydrocarbons (PAH). PAH are relatively non-polar organic compounds composed of fused benzene rings. PAH and their derivatives are ubiquitously distributed in the environment as a result of natural and anthropogenic processes. PAH occur as natural products in plants and microbes (Andelman and Snodgrass, 1972; National Academy of Sciences, 1972), but most PAH released into the environment result from fossil fuel combustion, oil spills, municipal sewage treatment effluents and industrial processes (Archer et al., 1979; Guerin, 1975).

As a class, PAH are of interest environmentally because of their potential health hazard to man. Numerous higher molecular weight PAH have been shown to be carcinogenic, teratogenic, and mutagenic in laboratory mammals and man (Neff 1978). Assessment of risks associated with the introduction of PAH into the environment depends in part upon quantification of environmental transport and subsequent exposure concentrations experienced by biotic components (Crawford and Leggett, 1980). With recent improvements in analytical techniques and the advent of sophisticated computer models, interest has been directed towards the origin, transport, fate and metabolism of PAH in the environment.

Thousands of different PAH compounds are chemically possible. Therefore, application of elaborate screening protocols (Duthie, 1977) to

individual PAH in order to estimate major processes of transport, accumulation and degradation would be impractical for purposes of risk assessment. Thus, the importance of developing predictive models of PAH fate in aquatic systems must be emphasized (Baughman and Lassiter, 1978). Large-scale complex microcosms, that incorporate important structural, functional and coupling properties of ecosystems, can be important tools for testing mathematical models of pollutant fate. Microcosms of this kind act best as a bridge between noninteractive laboratory tests and complex, highly interactive field experiments and environmental monitoring programs (Bowling et al., 1980) by providing the data sets necessary to evaluate and facilitate the development of predictive environmental fate models (Hill, 1979).

Anthracene was selected as a model PAH for this study because it is a commercially important PAH produced in large quantities and it is used extensively as a reagent in organic synthesis (Archer et al., 1979). Anthracene also has been used frequently as a model PAH for studies of environmental fate in aquatic systems (Ausmus et al., 1980) or physiological disposition in aquatic biota (Roubal et al., 1977), because it is considered noncarcinogenic (National Academy of Science, 1972; Sunshine, 1969) and relatively nontoxic (Sunshine, 1969; Deichmann and Gerarde, 1969). This study was designed to provide a data set that would describe the disposition of anthracene in the water and aufwuchs matrices of a large outdoor channel microcosm for the purposes of comparison with existing laboratory information and as an aid to those trying to develop and validate the Exposure Analysis Modeling System (EXAMS) (Burns et al., 1982). Two biologically colonized channels microcosms were used in this study; one received anthracene input while the other served as a control and received no

anthracene. The study was conducted for 40 days, from October 10 to November 18, 1981. This study was designed to collect a variety of environmental, physical and chemical data important in controlling processes believed significant in determining the fate of polycyclic aromatic hydrocarbons in the aquatic environment.

Two separate weekly sampling schedules were implemented to address questions about disposition of anthracene in the water and aufwuchs matrices of the channels. Water samples were collected at 1230h on days 9, 16, 23, 24, 30 and 37, at 0800h on days 24 and 30, and hourly from dawn to midday on day 30, while aufwuchs samples were collected at 0800h on days 4, 11, 18, 25, 32 and 40. Both matrices were analyzed to determine anthracene concentrations as well as concentrations of anthraquinone. Anthraquinone is the primary and most stable breakdown product of anthracene. Concentrations were measured only after the experimental channel had achieved a steady state condition with respect to loading in order to comply with one of the basic assumptions for using the EXAMS modeling system. Environmental data were collected by the staff at the channels microcosms facility as well as the meteorological research group permanently located on the SRP and operated as part of the Savannah River Laboratory (SRL).

SECTION 2

CONCLUSIONS

Anthracene concentrations in the water exhibited a similar response for the entire 36 day experimental period. Anthracene concentrations in the water showed significant diel variation. Maximum water concentrations were achieved and maintained throughout the channel during periods of darkness. However, anthracene concentrations decreased significantly with distance downstream during daylight hours. The major loss of anthracene from the channel was due to photolysis, with some loss attributable to volatilization. Other loss processes such as sorption and metabolism by aufwuchs were insignificant. Anthraquinone concentrations in water increased as anthracene concentrations decreased during daylight hours. However, anthraquinone did not account entirely for the observed anthracene losses, suggesting that other photolytic degradation products were being formed. Upon termination of anthracene input, concentrations in the water returned to background levels within 24 hours.

Aufwuchs accumulated anthracene and achieved maximum concentrations within 4 days of initiation of input. Anthracene concentrations in aufwuchs were similar throughout the length of the channel. Anthracene loss from the water due to aufwuchs uptake was small (~0.02% of total anthracene input). Aufwuchs did not accumulate anthraquinone from the water or as a result of metabolism of anthracene. The bioconcentration factor (BCF) calculated for aufwuchs was not significantly different with distance

downstream or through time (36 days). Anthracene depuration from aufwuchs was rapid with concentration returning to background levels within 72 hours, after termination of anthracene input.

Microcosms of the size and complexity studied here can provide data useful in verifying or validating results obtained in laboratory and modeling studies. However, microcosms of this nature are most effective and efficient when used as a research tool incorporated into an integrated research program involving rigorous laboratory experimentation as well as conceptual model development. With this type of interactive research all aspects of the program can gain sight from one another producing the opportunity to acquire information and/or understanding which has meaningful application. Lack of such an interactive approach however, severely diminishes the usefulness of large microcosms.

SECTION 3

RECOMMENDATIONS

Future studies of the disposition of photo-labile compounds in aquatic systems should be designed to illustrate the magnitude of diel variations in dissolved compound concentrations resulting from daily changes in the natural light intensity. Such studies should include close interval (hourly) sampling of major components within the test system to determine how these components track water concentrations on a diel cycle. Close interval sampling is most important for those components of the test system for which laboratory or literature data indicates rapid uptake and depuration rate constants or short half-lives. Future studies should address the potential for toxic effects on biota which could alter the structure and/or function of the test system. Such alterations could affect the dynamics and/or disposition of the compound of interest within a test system.

In the future, if large-scale microcosms are used as tools to verify or validate independently developed predictive models, there needs to be a conscious and concerted effort to establish the needed communication between both the modeling expertise and those with a knowledge of the design and operational constraints of the test facility. This communication is required to insure an appropriate experimental design and to provide the best possible test of the model. Large-scale microcosms can never be effective tools for verification or validation of laboratory studies or

predictive models if the wrong questions are asked or inadequate and inappropriate data is collected. If large-scale complex microcosms are perceived as relevant and valuable research tools for testing hypotheses about environmental functions, serious consideration should be given by funding agencies to establish a facility with the necessary funding structure to support and maintain the facility and expertise on a long term basis. Large-scale complex microcosms are too expensive to construct upon demand and too complex to understand during one or two years of operation.

SECTION 4

FACILITY DESCRIPTION

The channels microcosm facility (Figure 4.1) used for this study is located on the Department of Energy's (DOE) Savannah River Plant (SRP), a 507 km^2 reserve located on the upper coastal plain of South Carolina, USA.

The facility is a single pass system consisting of six separate cinder-block channels (Table 4.1), each 91.5 m long x 0.6 m wide x 0.3 m deep. The channels rest on a large concrete slab and are oriented in an east-west direction. A large pool, 10.2 m long x 3.1 m wide x 1.0 m deep, is located at the lower end of the facility to receive the effluent discharge. The channels were lined with 0.05 cm thick black polyvinyl chloride (PVC) plastic, and filled with 0.05 m of washed quartz sand substrate (Table 4.2). Water was pumped from the Tuscaloosa aquifer via a deep well located near the facility. Well water was treated to remove CO_2, and O_2 and hydrated lime were added to produce inorganic water quality similar to that of surface waters in the local upper coastal plain (Table 4.3). Water entered the channels through calibrated V-notch weirs and a depth of 20 cm was maintained by control gates at the discharge. Water flow rate was maintained at 75.7 $\ell \cdot min^{-1}$ yielding a calculated current velocity of 0.01 $m \cdot sec^{-1}$ and a turnover time of 2.54h. Effluent water from the channels was pumped from the tailpool to a large treatment tank where it was gravity fed through a filter of activated charcoal and gravel prior to release into the local environment. The channels were seeded daily for 3

months with slurries of natural water and sediments and allowed to colonize for 18 months prior to this study. The sides and bottom of each channel were covered completely with an aufwuchs mat 2-5 mm thick. The aufwuchs mat was of similar composition regardless of thickness (Table 4.4) and contained considerable dead material (~75%). Bluegreen algae were by far the dominant algal taxonomic group. The mat formed a blanket which covered the walls and bottom of the channels and in effect limited direct contact of the PVC liner material and sand substrate with the water column. Therefore, the aufwuchs mat on the bottom of the channel and the underlying quartz sand substrate were combined into a more descriptive term "channels sediment" that had the physical characteristics presented in Tables 4.5 and 4.6.

Two biologically colonized channels microcosms were used in this study. For conceptual and modeling purposes, each channel was divided into 5 segments (reaches) ~18.3 m long that were identified as reach 1 (beginning at the water input weir) through reach 5 (ending at the discharge). Sampling stations for water and aufwuchs were at three locations within reaches 1, 3 and 5: 1) two meters downstream from the beginning, 2) at the midpoint, and 3) two meters upstream from the end. Figure 4.2 depicts the relationship of all sampling stations within the channel, indicates their distance from input and gives their number designation.

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Figure 4.1. View of the channel microcosms facility.

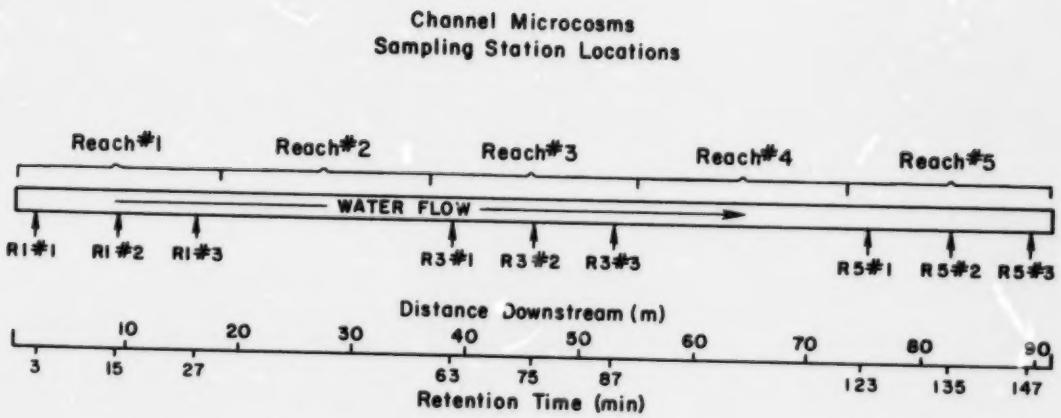

Figure 4.2. Sampling station locations.

TABLE 4.1. PHYSICAL PARAMETERS OF CHANNELS MICROCOSMS

Geographic Location:	Latitude 32°17'30" Longitude 81°42'30"
Orientation:	West to East (direction of flow)
Elevation:	85.65 m (281 ft above sea level)
Channel Dimensions:	91.5 m long 0.6 m wide 0.3 m deep
Water Depth:	0.2 m
Water Flow Rate:	75.7 $\ell \cdot min^{-1}$
Current Velocity:	0.01 $m \cdot sec^{-1}$
Retention Time:	2.54 h
Sand Sediment Depth:	0.05 m
Reaeration Rate:	0.20 $\pm$ 0.24 $gO_2 \cdot m^{-2} \cdot h^{-1}$ ($\bar{x} \pm$ 95% CI, n = 7) (Range of measured values 0.081 to 0.768 $gO_2 \cdot m^{-2} \cdot h^{-1}$ Knight, 1980)

TABLE 4.2. PHYSICAL-CHEMICAL PARAMETERS OF WASHED QUARTZ SAND SUBSTRATE[a]

Size Fraction Distribution:

Name of Fraction	Diameter Range	% Total Sample[b]
Very coarse sand	> 2 mm	14.01 ± 25.5
Coarse sand	< 2 mm > 1 mm	19.34 ± 24.5
Medium sand	< 1 mm > 0.5 mm	35.89 ± 3.3
Fine sand	< 0.5 mm > 0.25 mm	24.21 ± 2.7
Very fine sand, silt and clay	< 0.25 mm	6.15 ± 0.6

Bulk Density: 1.16 ± 0.05 $g \cdot cm^{-3}$

Water Content: 2.77 ± 0.4 %

Cation Exchange Capacity: 0.02 meq per 100 g[c]

[a] All determinations made on quartz sand substrate prior to biological colonization in channel microcosms using techniques outlined by Black (1965).

[b] $\bar{x} \pm$ 95% CI, n = 3

[c] Determination made using method outlined by Page (1982).

TABLE 4.3. WATER QUALITY PARAMETERS FOR TREATED CHANNEL MICROCOSMS WATER[a]

Total alkalinity	17.5 $mg \cdot \ell^{-1}$ as $CaCO_3$
Hardness	21.5 $mg \cdot \ell^{-1}$ as $CaCO_3$
pH	6.6
Specific conductance	31 $\mu mho \cdot cm^{-1}$
Ionic strength (I)	2.5×10^{-4} M
Dissolved oxygen (DO)	8.5 $mg \cdot \ell^{-1}$
CO_2	3.25 $mg \cdot \ell^{-1}$
SO_4^{-2}	1.9 $mg \cdot \ell^{-1}$
Total P	10.1 $\mu g \cdot \ell^{-1}$
Nitrogen (NO_2 + NO_3)	19.2 $\mu g \cdot \ell^{-1}$
Ca	3.17 $mg \cdot \ell^{-1}$
Cl^-	2.9 $mg \cdot \ell^{-1}$
Total Organic Carbon (TOC)[b]	3.3 $mg \cdot \ell^{-1}$
Total Inorganic Carbon (TIOC)[b]	2.9 $mg \cdot \ell^{-1}$
Total dissolved solids (TDS)	20.5 $mg \cdot \ell^{-1}$

[a] All determinations made on treated well water prior to introduction into channel microcosm using methods outlined by Greenberg et al. (1980).

[b] Determinations were made on water samples collected at 9 m and 89 m from the experimental channel using a Beckman Model 915 Total Organic Carbon Analyzer.

TABLE 4.4. AUFWUCHS COMMUNITY COMPOSITION

Algal Group	Taxon	Growth Form	Organisms·m^{-1} Reach 1	Reach 3	Reach 5
B.G.[a]	Seytonema carolinanum	fil.[b]	641	1282	1282
B.G.	Aphanothece sp.	col.[c]	4808	5929	4487
B.G.	Phormidium sp.	fil.	9296	801	1282
B.G.	Nostoc sp.	col.*	12181	641	641
B.G.	Misc. single bluegreen	cells	104175	80135	88148
Diatom	Achnanthes minntissima	cell[d]	3686	160	801
Green	Chlamydomanas sp.	cell	160	160	-
Diatom	Navicula sp.	cell	-	160	321
Green (Desmid)	Cosmarium sp.	cell	-	160	-
Green	Scenedesmus sp.	cell	-	-	641
B.G.	Oscillatoria sp.	fil.	-	-	160

[a] Bluegreen algae

[b] Filament

[c] Colonial

[d] Unicellular

* Nostoc sp. colonies were comprised of ~10 filaments containing ~15 cells each.

TABLE 4.5. PHYSICAL PARAMETERS OF CHANNEL SEDIMENTS

Wet Weight: ($g \cdot cm^{-3}$)	
Reach 1	2.062 ± 0.2[a]
Reach 3	1.921 ± 0.2
Reach 5	1.936 ± 0.09
Bulk Density: ($g \cdot cm^{-3}$)	
Reach 1	1.606 ± 0.1
Reach 3	1.492 ± 0.1
Reach 5	1.483 ± 0.07
Ash-Free Dry Weight: ($g \cdot cm^{-3}$)	
Reach 1	0.0016 (n = 2)
Reach 3	0.0019 ± 0.001
Reach 5	0.0028 ± 0.001
Water Content: (%)	
Reach 1	22.09 ± 1.6
Reach 3	22.31 ± 2.4
Reach 5	23.37 ± 2.7

[a] $\bar{x} \pm$ 95% CI, n = 3

TABLE 4.6. CHANNEL SEDIMENT DATA

Sample ID	Wet Wt. (g)	Dry Wt. (g)	Volume (cm^3)	Bulk Density ($g \cdot cm^{-3}$)	Ash Wt. (g)	Ash-free Dry Wt. (g)
R1[a]-1[b]	50.88	39.9484	24.95	1.601	-	-
R1-2	52.81	40.7774	24.42	1.670	40.7278	0.0496
R1-3	46.38	36.1705	23.36	1.548	36.1443	0.0262
R3-1	41.39	31.7025	20.71	1.531	31.6711	0.0314
R3-2	39.10	30.5691	21.24	1.439	30.5266	0.0425
R3-3	44.95	35.1961	23.36	1.507	35.1428	0.0533
R5-1	36.21	28.0975	18.58	1.512	28.0561	0.0414
R5-2	40.22	30.9145	21.24	1.456	30.8567	0.0578
R5-3	37.55	28.3247	19.11	1.482	28.2603	0.0644

[a] Sampling reach identification number.

[b] Sampling station designation within the sampling reach.

SECTION 5

ANTHRACENE INPUT PROCEDURE

Anthracene was introduced for 36 days into the treatment channel from stock solutions via peristaltic pump. Stock solutions (528.4 $\pm$ 0.01 $mg \cdot \ell^{-1}$; $\bar{x} \pm$ 95% CI, n = 36) (Table 5.1) were prepared by dissolving 2.0 g of crystalline anthracene (Aldrich Chemical Co.; purity > 98%) in 3.785ℓ (1 gal) of pharmaceutical grade ethanol. Stock solutions were prepared daily and kept in the dark. Stock solutions were pumped through stainless steel tubing directly into the turbulent mixing zone of the channel below the water input weir. Stock was introduced at a rate of 2.41 $\pm$ 0.05 $m\ell \cdot min^{-1}$ ($\bar{x} \pm$ 95% CI, n = 36). The theoretical anthracene concentration in the water at input, based on the weight of reagent anthracene dissolved in the stock and the appropriate dilution factors, was 16.40 $\pm$ 0.9 $\mu g \cdot \ell^{-1}$ ($\bar{x} \pm$ 95% CI, n = 36) (Table 5.1). The nominal anthracene water concentration at input, based upon two separate assays of each stock solution and the daily input pumping rate, was 16.5 $\pm$ 0.4 $\mu g \cdot \ell^{-1}$ ($\bar{x} \pm$ 95% CI, n = 36) (Table 5.2). The nominal ethanol concentration in the water was 25.7 $\pm$ 0.5 $mg \cdot \ell^{-1}$ ($\bar{x} \pm$ 95% CI, n = 36). The mean measured anthracene concentration at input (station R1-1) was 14.7 $\pm$ 0.4 $\mu g \cdot \ell^{-1}$ ($\bar{x} \pm$ 95% CI, n = 10) (Table 9.2A).

TABLE 5.1. THEORETICAL ANTHRACENE WATER CONCENTRATION BASED ON THE CALCULATED DAILY INPUT PUMP RATE AND THE WEIGHT OF ANTHRACENE DISSOLVED TO MAKE STOCK SOLUTIONS

Experimental Date	Stock input pump rate ($ml \cdot min^{-1}$)	Dry Weight of Anthracene Reagent (g)	Anthracene Concentration of Stock ($ng \cdot \mu\ell^{-1}$)	Calculated Anthracene Input Concentration ($\mu g \cdot \ell^{-1}$)	Calculated Anthracene Input ($nmoles \cdot \ell^{-1}$)
10/12/81	2.31	1.9999	528.4	16.1	90.5
10/13	2.49	2.0005	528.5	17.4	97.6
10/14	2.47	2.0001	528.4	17.2	96.8
10/15	2.44	2.0002	528.4	17.0	95.6
10/16	2.43	1.9998	528.4	17.0	95.2
10/17	2.55	1.9996	528.3	17.8	99.8
10/18	1.68	2.0002	528.4	11.7	65.8
10/19	2.39	1.9997	528.3	16.7	93.6
10/20	2.30	1.9998	528.4	16.0	90.1
10/21	2.50	1.9999	528.4	17.4	97.9
10/22	2.60	1.9998	528.4	18.1	102.0
10/23	2.23	2.0003	528.5	15.6	87.4
10/24	2.37	2.0000	528.4	16.5	92.8
10/25	2.47	2.0000	528.4	17.2	96.7
10/26	2.46	2.0000	528.4	17.2	96.4
10/27	2.53	2.0000	528.4	17.7	99.1
10/28	2.50	2.0001	528.4	17.4	97.9
10/29	2.47	2.0001	528.4	17.2	96.8
10/30	2.47	1.9999	528.4	17.2	96.7
10/31	2.43	2.0001	528.4	17.0	95.2
11/1/81	2.40	2.0000	528.4	16.8	94.0
11/2	2.40	2.0000	528.4	16.8	94.0
11/3	2.41	2.0001	528.4	16.8	94.4
11/4	2.46	2.0000	528.4	17.2	96.4
11/5	2.20	2.0000	528.4	15.4	86.2
11/6	2.38	2.0000	528.4	16.6	93.2

(Continued)

TABLE 5.1. Continued

11/7	2.37	1.9999	528.4	16.5	92.8
11/8	2.35	2.0000	528.4	16.4	92.0
11/9	2.45	2.0000	528.4	17.1	96.0
11/10	2.46	2.0001	528.4	17.2	96.4
11/11	2.48	2.0000	528.4	17.3	97.1
11/12	2.43	2.0000	528.4	17.0	95.2
11/13	2.46	2.0000	528.4	17.2	96.4
11/14	2.41	2.0000	528.4	16.8	94.4
11/15	2.40	2.0000	528.4	16.8	94.0
11/16	2.43	2.0000	528.4	17.0	95.2
$\bar{x}$	2.41	2.0000	528.4	16.8	94.2
s	0.148	0.00016	0.03381	1.03	5.80
n	36	36	36	36	36
95%CI	0.050	0.00005	0.01144	0.349	1.96

Channel flow rate 75.7 $\ell \cdot min^{-1}$

TABLE 5.2. NOMINAL DAILY ANTHRACENE WATER CONCENTRATION BASED ON THE CALCULATED DAILY INPUT PUMP RATE AND THE AVERAGE MEASURED ANTHRACENE CONCENTRATION FOR EACH DAYS STOCK SOLUTION

Experimental Date	Stock input pump rate ($ml \cdot min^{-1}$)	Average Measured Stock Concentration ($ng \cdot \mu\ell^{-1}$)	Calculated Anthracene Input Concentration ($\mu g \cdot \ell^{-1}$)	Calculated Anthracene Input ($nmoles \cdot \ell^{-1}$)
10/12/81	2.31	522.4	15.9	89.4
10/13	2.49	522.1	17.2	96.4
10/14	2.47	536.3	17.5	98.2
10/15	2.44	529.2	17.1	95.7
10/16	2.43	528.0	17.0	95.1
10/17	2.55	510.2	17.2	96.4
10/18	1.68	520.2	11.5	64.8
10/19	2.39	516.6	16.3	91.5
10/20	2.30	506.3	15.4	86.3
10/21	2.50	527.3	17.4	97.7
10/22	2.60	525.2	18.0	101.0
10/23	2.23	520.7	15.3	86.1
10/24	2.37	511.6	16.0	89.9
10/25	2.47	520.9	17.0	95.4
10/26	2.46	522.0	17.0	95.2
10/27	2.53	512.8	17.1	96.2
10/28	2.50	507.7	16.8	94.1
10/29	2.47	499.4	16.3	91.4
10/30	2.47	499.9	16.3	91.5
10/31	2.43	521.0	16.7	93.8
11/1/81	2.40	538.0	17.1	95.7
11/2	2.40	549.2	17.4	97.7
11/3	2.41	537.3	17.1	96.0
11/4	2.46	542.0	17.6	98.8
11/5	2.20	514.0	14.9	83.8
11/6	2.38	507.5	16.0	89.5
11/7	2.37	539.4	16.9	94.8
11/8	2.35	504.8	15.7	87.9
11/9	2.45	508.4	16.4	92.3
11/10	2.46	505.6	16.4	92.2
11/11	2.48	516.2	16.9	94.9
11/12	2.43	516.4	16.6	93.0
11/13	2.46	523.4	17.0	95.4
11/14	2.41	505.4	16.1	90.3
11/15	2.40	520.0	16.5	92.5
11/16	2.43	516.9	16.6	93.1
$\bar{x}$	2.41	519.6	16.5	92.6
s	0.148	12.26	1.10	6.09
n	36	36	36	36
95%CI	0.050	4.150	0.371	2.06
		21		

SECTION 6

PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS FOR ANTHRACENE

Chemical formula: $C_{14}H_{10}$	(CRC Press, 1980)
Molecular weight: 178.24	(CRC Press, 1980)
Density: $1.283^{25/4}$	(CRC Press, 1980)
Melting point: 218°C	(CRC Press, 1980)
Boiling point: 342°C	(CRC Press, 1980)
Water solubility: 73 $\mu g \cdot \ell^{-1}$ (25°C)	(Karickoff, S. W., et al., 1979)
Vapor pressure: 1.95×10^{-4} Torr	(Jordan, T. E., 1954)
Vapor concentration: 1.05×10^{-8} moles$\cdot m^{-3}$ 25°C	(Jordan, T. E., 1954)
Henry's law constant: $2.66 \pm 0.07 \times 10^{-3}$	(Southworth, G. R., 1979)
Volatilization rate:	
$0.011\ h^{-1}$	(estimated using volatilization half-life reported by Herbes, S.E. et al., 1980; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)
0.0023 to $0.039\ h^{-1}$ (depending on wind speed and current velocity; wind speed 0 to 4 $m \cdot sec^{-1}$, current velocity 0 to 1 $m \cdot sec^{-1}$)	(estimated using volatilization half-life reported by Southworth, G. R., 1979[b]; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)
0.14 (unitless calculated as a function of reaeration rate	(Zepp, R. G., 1979)
Volatilization half-life:	
62 h	(Herbes, S. E. et al., 1980)

18 h to 300 h
(depending on wind speed and current velocity; wind speed 0 to 4 $m \cdot sec^{-1}$ current velocity 0 to 1 $m \cdot sec^{-1}$)

(Southworth, G. R. 1979[b])

Spectral properties:

(Anthracene in EtOH-MeOH)

(Clar, E. 1964)

λ max nm	log e
308	3.15
323	3.47
338	3.75
355	3.86
375	3.87

Dissappearance quantum yield:

$3.0 \pm 0.2 \times 10^{-3}$

(Zepp, R. G., P. F. Schlotzhauer 1979)

Specific sunlight absorption rate:

$0.83\ sec^{-1}$

(Zepp, R. G., P. F. Schlotzhauer 1979)

Singlet oxygen photosensitized rate:

$0.003\ h^{-1}$
(for midday, midsummer, 360 nm)

(Zepp, R. G., P. F. Schlotzhauer 1979)

Photolysis rate:

$0.924\ h^{-1}$

(estimated using photolysis half-life reported by Herbes, S. E. et al, 1980; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)

$0.433\ h^{-1}$
(for summer)

(estimated using photolysis half-life reported by Southworth, G. R. 1979); using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)

$0.144\ h^{-1}$
(for winter)

(estimated using photolysis half-life reported by Southworth, G. R. 1979; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)

$0.924\ h^{-1}$ (for midday, midsummer)	(estimated using photolysis half-life reported by Zepp, R. G., P. F. Schlotzhauer, 1979; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)
$0.202\ h^{-1}$ (overall)	(Zepp, R. G., P. F. Schlotzhauer, 1979)

Photolysis half-life:

0.75 h	(Herbes, S. E. et al., 1980)
1.6 h (for summer)	(Southworth, G. R., 1979)
4.8 h (for winter)	(Southworth, G. R., 1979)
0.75 h (for midday, midsummer, at 360 nm)	(Zepp, R. G., P. F. Schlotzhauer, 1979)

Octanol/water partition coefficient, K_{ow}:

K_{ow} 28200 $25°C$	(Leo, A. et al. 1971)
log K_{ow} 4.45	
K_{ow} 22000 $25°C$	(Kenaga, E. E., C. A. I.
log K_{ow} 4.30	Goring, 1980)

Soil adsorption coefficient:

26000 (K_{oc})	(Karickhoff, S. W. et al. 1979)
25000 (K_d) (autoclaved yeast as organic particulate)	(Herbes, S. E., 1977)
1600 (K_d) (clay fraction 2.0 to 0.1 μm)	(Southworth, G. R., 1979b)
~100 (K_d) (silt fraction 5 to 10 mm)	(Southworth, G. R., 1979b)

Natural stream bed organic sediment; uptake rate K_u, elimination rate K_d (calculations on a mass basis, ($\bar{x} \pm 2SE$, n = 3); Giesy J. P., et al. 1982)

$K_u = 1.37 \pm 0.14\ h^{-1}$	(estimated using uptake data)
$K_d = 0.0046 \pm 0.0012 h^{-1}$	(estimated using uptake data)

$K_d = 0.0023 \pm 0.0004 h^{-1}$ (estimated using elimination data)

Bioaccumulation: (uptake rate, K_u; elimination rate, K_d; elimination half-life, $T_{\frac{1}{2}}$; bioconcentration factor, BCF)

Periphyton (Aufwuchs) (Haddock, et al., 1982; unpublished data)

$K_u = 207.8 \text{ ml} \cdot g^{-1} \cdot h^{-1}$

$K_d = 0.131 \ h^{-1}$

$T_{\frac{1}{2}} = 5.3h$ (estimated using elimination rate K_d; using $T_{\frac{1}{2}} = .693 \cdot K_d^{-1}$)

BCF 1456 (laboratory measured)
1586 (estimated from uptake data)
1261 ± 96 (channels microcosm observed $\bar{x} \pm$ 95%C.I.; n = 45)

Daphnia pulex (Southworth, 1979b; $\bar{x} \pm$ 1SE)

$K_u = 0.702 \pm 0.077 \text{ ml} \cdot g^{-1} \cdot h^{-1}$

$K_d = 0.589 \pm 0.077 \ h^{-1}$

$T_{\frac{1}{2}} = 1.2$ h

BCF = 1192 ± 52
353 ± 48 (Leversee, et al. 1982)
(DOC range 0.2 to 6.0 $mg \cdot \ell^{-1}$; Daphnia magna)

Chiromomus riparius (Giesy et al., 1982; $\bar{x} \pm$ 95% C.I.)

$K_u = 141.4 \pm 28 \text{ ml} \cdot g^{-1} \cdot h^{-1}$

$K_d = 0.078 \pm 0.018 \ h^{-1}$ (estimated using uptake data)

$K_d = 0.262 \pm 0.055 \ h^{-1}$ (estimated using elimination data)

$T_{\frac{1}{2}} = 2.7$ to 8.9 h

BCF = 1840 ± 77 (not corrected for bio-transformation as noted by authors)

Pimephales promelas (Southworth, 1979b; $\bar{x} \pm$ 1SE)

$K_u = 0.031 \pm 0.025\ ml \cdot g^{-1} \cdot h^{-1}$

$K_d = 0.064 \pm 0.059\ h^{-1}$

$T_{\frac{1}{2}} = 10.8\ h$

$BCF = 480 \pm 96$

Lepomis macrochirus (Spacie, 1982)

$K_u = 36\ ml \cdot g^{-1} \cdot h^{-1}$

$K_d = 0.04\ h^{-1}$

$T_{\frac{1}{2}} = 17\ h$

$BCF = 900$ (not corrected for biotransformation as noted by authors)

SECTION 7

ENVIRONMENTAL DATA

Data necessary for accurate estimation of environmental removal or chemical transformation processes, such as volatilization, photolysis, hydrolysis, and adsorption, were collected by both the staff at the channels microcosms facility and the meteorological research group supported by the Savannah River Laboratory (SRL) located on the SRP. Parameters for which data were collected were: air and water temperature, precipitation, relative humidity, wind speed, solar irradiance, solar illumination and % cloud cover. Data collected by the SRL meteorological group represent reportings from a permanent SRL weather sampling station ~ 2 miles east of the channels microcosms facility.

Water temperature was measured daily at 0800h, 1230h and 1600h from the mid-point station of reaches 1, 3 and 5 (Table 7.1). Table 7.2 represents a summary of all water temperature data by reach and sampling time for the experimental period.

Air temperature was measured at the channels microcosms facility daily at 0800h, 1230h and 1600h. The daily high and low temperature readings for the experimental period were supplied by the SRL meteorological group. The SRL temperature data were collected continuously and recorded using a hydrothermograph. The high and low temperature: (Table 7.3) do not correspond to a particular time of day but are recorded as they occur during any given 24h sampling period.

TABLE 7.1. WATER TEMPERATURE DATA (°C)

Experimental Date	Reach 1			Reach 3			Reach 5		
	0800h	1230h	1600h	0800h	1230h	1600h	0800h	1230h	1600h
10/12/81	20.0	21.5	21.5	19.0	22.0	21.5	18.5	22.5	22.0
10/13	20.0	21.0	21.0	18.5	20.5	21.0	17.5	20.0	21.0
10/14	19.0	-	21.5	18.0	-	22.5	16.5	-	23.5
10/15	21.0	22.0	-	19.0	22.5	-	18.5	22.5	-
10/16	21.0	-	22.0	-	-	23.5	19.0	-	25.0
10/17	21.0	22.0	-	20.0	23.0	-	19.0	23.0	-
10/18	21.0	22.0	-	-	-	-	20.0	22.0	-
10/19	20.0	22.0	-	19.0	22.0	-	17.0	21.5	-
10/20	20.0	-	-	18.5	-	-	16.5	-	-
10/21	20.0	21.0	21.0	19.0	22.0	21.0	17.0	22.0	22.0
10/22	20.5	22.0	22.0	20.0	23.0	23.0	19.0	23.0	23.5
10/23	22.0	22.0	22.0	21.0	23.0	22.0	21.0	24.0	23.0
10/24	20.0	20.0	-	19.0	19.0	-	18.0	18.0	-
10/25	20.0	19.0	20.0	-	-	-	12.0	11.0	18.0
10/26	20.0	20.5	-	20.0	21.0	-	19.0	21.0	-
10/27	21.0	21.0	-	21.0	23.0	-	21.0	23.0	-
10/28	20.5	-	-	20.0	-	-	19.0	-	-
10/29	21.0	-	-	20.5	-	-	19.5	-	-
10/30	20.0	21.0	-	-	-	-	18.0	19.5	-
10/31	20.0	-	-	-	-	-	18.0	-	-
11/1/81	20.0	-	-	-	-	-	19.0	-	-
11/2	20.5	-	-	19.0	-	-	18.5	-	-
11/3	21.0	22.0	-	-	-	-	20.0	22.0	-
11/4	21.0	-	-	20.5	-	-	19.5	-	-
11/5	21.0	-	21.0	21.0	-	22.0	20.5	-	22.0
11/6	21.0	-	-	20.0	-	-	19.0	-	-
11/7	20.0	-	-	-	-	-	17.5	-	-
11/8	20.0	-	-	-	-	-	12.0	-	-
11/9	20.0	-	21.0	18.5	-	22.0	17.0	-	22.0
11/10	20.5	-	-	20.0	-	-	19.0	-	-
11/11	20.0	-	-	18.5	-	-	18.0	-	-
11/12	20.0	-	-	18.0	-	-	16.0	-	-
11/13	20.0	-	-	17.5	-	-	16.0	-	-
11/14	19.0	-	-	17.0	-	-	16.0	-	-
11/15	19.5	-	-	18.0	-	-	16.0	-	-
11/16	-	-	-	-	-	-	-	-	-

TABLE 7.2. MEAN WATER TEMPERATURE VALUES (°C)

	REACH 1	REACH 3	REACH 5	Overall Mean for Channel
0800h	$\bar{x}$ = 20.3 s = 0.6 n = 35 95%CI = 0.2	$\bar{x}$ = 19.2 s = 1.1 n = 26 95%CI = 0.4	$\bar{x}$ = 17.9 s = 2.0 n = 35 95%CI = 0.7	$\bar{x}$ = 19.2 s = 1.2 n = 3 95%CI = 3.0
1230h	$\bar{x}$ = 21.3 s = 0.9 n = 15 95%CI = 0.5	$\bar{x}$ = 21.9 s = 1.3 n = 11 95%CI = 0.9	$\bar{x}$ = 21.0 s = 3.2 n = 15 95%CI = 1.8	$\bar{x}$ = 21.4 s = 0.5 n = 3 95%CI = 1.8
1600h	$\bar{x}$ = 21.3 s = 0.6 n = 10 95%CI = 0.4	$\bar{x}$ = 22.1 s = 0.8 n = 9 95%CI = 0.7	$\bar{x}$ = 22.2 s = 1.9 n = 10 95%CI = 1.3	$\bar{x}$ = 21.8 s = 0.5 n = 3 95%CI = 1.2
Overall Mean for Reach	$\bar{x}$ = 21.0 s = 0.6 n = 3 95%CI = 1.4	$\bar{x}$ = 21.1 s = 1.6 n = 3 95%CI = 3.9	$\bar{x}$ = 20.4 s = 2.2 n = 3 95%CI = 5.5	$\bar{x}$ = 20.8 s = 1.4 n = 9 95%CI = 1.1

TABLE 7.3. AIR TEMPERATURE DATA (°C)

Experimental Date	Measured Channels Values (°C) 0800h	1230h	1600h	Reported SRP Values (°C) High	Low
10/12/81	12.0	23.0	22.0	19.4	9.4
10/13	10.0	17.0	20.5	18.9	7.8
10/14	10.5	-	24.0	21.7	7.8
10/15	12.5	-	-	25.0	10.6
10/16	16.0	-	-	27.2	10.6
10/17	-	-	-	27.8	13.9
10/18	20.0	-	-	25.6	13.9
10/19	9.5	20.0	-	20.0	6.7
10/20	2.5	-	-	22.2	1.7
10/21	9.0	23.0	26.0	26.1	7.2
10/22	12.5	26.0	28.0	26.1	12.2
10/23	18.0	27.0	24.0	24.4	12.8
10/24	10.5	13.5	-	12.8	7.2
10/25	8.5	8.5	10.0	9.4	6.1
10/26	14.5	25.0	-	23.3	9.4
10/27	20.0	23.5	-	25.0	13.3
10/28	11.5	-	-	24.4	7.8
10/29	15.5	-	-	22.2	11.1
10/30	15.0	18.5	-	16.7	11.1
10/31	14.0	-	-	18.9	11.1
11/1/81	15.5	-	-	18.9	11.1
11/2	15.0	-	-	23.9	12.2
11/3	18.0	25.5	-	23.9	16.7
11/4	17.5	-	-	26.1	15.6
11/5	18.5	-	21.5	21.7	13.3
11/6	14.0	-	-	21.7	10.6
11/7	10.0	-	-	20.6	3.3
11/8	6.5	-	-	22.8	2.2
11/9	2.5	23.5	-	20.6	5.6
11/10	15.0	-	-	18.3	12.8
11/11	10.0	-	-	20.0	8.3
11/12	11.0	-	-	17.2	6.1
11/13	6.0	-	-	15.0	1.7
11/14	3.5	-	-	18.9	-1.7
11/15	5.0	-	-	22.8	0.6
11/16	-	-	-	20.0	7.2
Mean Air Temperature Values					
$\bar{x}$	12.1	21.1	22.0	21.4	8.8
s	4.8	5.4	5.4	4.0	4.4
n	34	13	8	36	36
95%CI	1.7	3.3	4.6	1.4	1.5

Daily precipitation and relative humidity data were supplied by the SRL meteorological group (Table 7.4). The daily precipitation data represents one reading at 24h intervals and was recorded at ~0800h. Relative humidity was measured continuously using a hydrothermograph. The relative humidity values (Table 7.4) correspond to the high and low temperature readings (Table 7.3) and represent the range of values during a given 24h sampling interval.

Wind speed data were supplied by the SRL meteorological group (Table 7.5). Wind speed measurements were collected by a remote monitoring telemetry system which continuously monitors wind speeds at various locations and altitudes and inputs the measurements directly into a computer system which generates 15 min and hourly mean wind speed summaries for each sampling location. All wind speed data (Table 7.5) were measured at a height of 10m. Therefore, all wind speed data must be converted to surface speeds before use in modeling volatiliation, water surface roughness, etc., as outlined in the EXAMS user manual (Burns et al, 1982). Table 7.5 represents a summary of wind speed data collected during the experimental period, using only the hourly mean values reported by the SRL system.

Solar irradiance was determined using a Belfort Instrument Company Pyranograph (Table 7.6). The 24h total solar irradiance values were determined by integrating the area of the chart paper (cm^2) under the 24h profile curve using a Li-cor unit area meter and then dividing the integrated area by the calibration area of 1 $gcal \cdot cm^{-2} \cdot d^{-1}$ as determined from the recorder chart paper. The 24h maximum solar irradiance values were read directly from the recorder chart for each 24h sampling interval. The 24h solar maximum values do not necessarily correspond with the midday

TABLE 7.4. PRECIPITATION (cm) AND RELATIVE HUMIDITY (%) DATA

Experimental Date	Daily Precipitation (cm)	Relative Humidity (%) At Daily High and Low Temp	
		High	Low
10/12/81	0.00	40	98
10/13	0.00	35	86
10/14	0.00	43	86
10/15	0.00	31	98
10/16	0.00	35	100
10/17	0.00	34	97
10/18	0.00	52	45
10/19	0.00	23	58
10/20	0.00	19	91
10/21	0.00	34	97
10/22	0.00	43	100
10/23	0.00	57	91
10/24	0.46	91	100
10/25	1.14	100	100
10/26	0.18	94	100
10/27	0.00	42	95
10/28	0.00	35	100
10/29	0.00	43	98
10/30	0.00	70	99
10/31	0.00	52	90
11/1/81	0.00	69	88
11/2	0.00	44	100
11/3	0.00	45	86
11/4	0.00	47	81
11/5	0.01	64	100
11/6	0.00	30	40
11/7	0.00	21	84
11/8	0.00	19	94
11/9	0.04	60	100
11/10	0.00	63	100
11/11	0.00	31	98
11/12	0.00	25	48
11/13	0.00	23	64
11/14	0.00	16	80
11/15	0.00	22	94
11/16	0.06	37	66

Total Precipitation During Experiment	Mean Relative Humidity Values		
1.89	$\bar{x}$	44	88
	s	21	17
	n	36	36
	95%CI	7	6

TABLE 7.5. WIND SPEED DATA ($m \cdot sec^{-1}$)

Experimental Date	0800h	1230h	1600h	24h Mean	1SD	n
10/12/81	5.2	4.7	5.5	4.8	0.67	24
10/13	5.4	5.4	6.3	5.7	0.87	23
10/14	6.1	5.5	4.4	5.0	1.4	24
10/15	5.8	5.1	3.4	4.6	1.1	20
10/16	5.0	4.6	3.5	3.8	1.1	21
10/17	5.0	4.9	1.7	3.2	1.4	19
10/18	4.6	4.9	5.9	5.5	1.0	24
10/19	5.5	5.6	4.7	5.2	1.1	24
10/20	3.5	5.3	3.5	3.2	1.1	24
10/21	4.3	4.7	2.6	3.5	1.4	23
10/22	4.5	4.4	2.7	3.7	0.76	24
10/23	3.4	2.8	5.0	3.6	0.74	20
10/24	5.4	6.2	5.1	4.8	1.0	24
10/25	5.0	4.9	2.8	4.3	0.82	24
10/26	3.7	2.8	3.4	3.7	0.96	24
10/27	4.3	4.5	6.3	4.6	0.86	24
10/28	4.2	5.1	2.9	3.8	1.4	24
10/29	2.9	6.3	5.0	4.4	1.1	24
10/30	4.7	4.9	5.7	4.8	0.42	24
10/31	5.3	5.6	5.9	5.2	0.44	24
11/1/81	5.4	4.4	4.6	5.0	0.87	24
11/2	5.2	5.4	3.7	4.0	1.0	24
11/3	3.6	3.3	2.9	3.3	0.78	24
11/4	3.2	4.3	2.2	3.2	0.83	24
11/5	3.6	2.9	2.6	2.8	0.57	24
11/6	3.7	4.6	4.9	4.3	1.7	24
11/7	3.8	4.3	2.3	4.3	1.4	24
11/8	2.0	5.4	1.9	2.6	1.2	24
11/9	2.9	2.3	1.6	2.8	1.4	24
11/10	3.1	3.6	1.8	3.4	0.83	24
11/11	5.1	4.1	5.1	5.2	0.73	24
11/12	6.9	5.6	5.0	6.2	1.0	24
11/13	4.5	5.1	4.0	5.3	1.2	24
11/14	4.9	3.2	4.4	4.9	1.2	24
11/15	3.9	2.9	2.9	4.1	1.4	24
11/16	4.1	4.1	0.6	2.8	2.2	24

Mean Wind Speed Values ($m \cdot sec^{-1}$)

$\bar{x}$	4.4	4.6	3.8	4.2
s	1.0	1.0	1.5	0.92
n	36	36	36	36
95%CI	0.35	0.34	0.51	0.31

TABLE 7.6. SOLAR IRRADIANCE DATA

Experimental Date	0800h	1230h	1600h	24h Max	24h Total	% Cloud Cover
	(gcal·cm^{-2}·min^{-1})				(gcal·cm^{-2}·d^{-1})	
10/12/81	.20	.92	.66	1.10	358	0
10/13	.10	.92	.55	0.92	320	0
10/14	.20	.90	.49	0.90	321	0
10/15	.25	.89	.50	0.90	317	0
10/16	.21	.87	.54	0.90	289	10
10/17	.23	.86	.47	0.86	288	10
10/18	.14	.92	.20	1.02	226	30
10/19	.29	.89	.55	0.89	319	0
10/20	.30	.87	.46	0.88	294	10
10/21	.06	.91	.47	0.95	258	20
10/22	.13	.93	.50	0.97	256	20
10/23	.09	.97	.43	0.98	206	40
10/24	.06	.19	.10	0.55	88	70
10/25	.01	.10	.09	0.30	46	90
10/26	.02	.48	.22	0.82	124	60
10/27	.14	.71	.11	0.86	245	20
10/28	.21	.71	.06	0.75	249	20
10/29	.32	.74	.09	0.85	228	30
10/30	.07	.40	.09	0.40	999	70
10/31	.17	.72	.11	0.79	224	30
11/1/81	.24	.97	.13	0.97	164	30
11/2	.28	.71	.14	0.97	218	30
11/3	.31	.72	.10	0.92	194	20
11/4	.23	.51	.14	0.66	164	30
11/5	.04	.30	.24	0.86	113	50
11/6	.21	.72	.30	0.72	239	0
11/7	.28	.73	.27	0.73	248	0
11/8	.26	.72	.31	0.72	255	0
11/9	.14	.43	.12	0.83	164	30
11/10	.02	.54	.14	0.89	137	40
11/11	.10	.63	.04	0.65	201	20
11/12	.01	.67	.05	0.69	230	10
11/13	.36	.36	.07	0.73	238	0
11/14	.40	.60	.06	0.75	232	10
11/15	.36	.64	.08	0.67	238	0
11/16	.38	.33	.02	0.84	176	30

	Mean Irradiance Values				
	0800h	1230h	1600h	24h Max	24h Total
$\bar{x}$	0.19	0.68	0.25	0.81	221
s	0.11	0.23	0.19	0.16	72
n	36	36	36	36	36
±95%CI	0.04	0.08	0.06	0.05	24

hours depending on the cloud cover for a particular day. Percent cloud cover was calculated using the 24h total irradiance values and the mean solar irradiance values for the month of October and November (330.8 and 248.6 g $cal \cdot m^{-2} \cdot d^{-1}$ respectively) as reported for the Augusta, Ga, National Oceanic and Atmospheric Administration (NOAA) weather station (Knapp et al., 1980). Percent cloud cover was calculated by taking the difference between the appropriate NOAA monthly mean value and the channel's measured total value, and dividing by the appropriate NOAA value, and then multiplying by 100. These values have been rounded to the nearest 10%, with a range from 0 (clear sky) to 10 (full cloud cover), and are reported in Table 7.6.

Solar illumination ($lumens \cdot m^{-2}$) was measured at the channel microcosms facility using a Weston Instruments Illumination Meter (Table 7.7). Mean solar illumination values (Table 7.7) provide an estimate of the solar illumination profile for an average day during the experimental period.

TABLE 7.7. SOLAR ILLUMINATION DATA (lumens·m^{-2}) x 10^4

	0800h	0900h	1000h	1100h	1200h	1300h	1400h	1500h	1600h	1700h
10/12/81	0.85	2.96	4.41	7.97	-	8.83	10.98	-	3.23	0.71
10/13	0.70	-	-	6.89	9.15	-	-	-	-	3.23
10/14	0.61	-	5.60	-	-	-	7.00	-	3.66	-
10/15	0.51	-	4.31	-	8.61	-	-	-	4.52	-
10/16	1.22	-	3.44	-	-	-	9.36	-	2.15	-
10/17	1.18	-	4.41	-	8.83	-	8.72	-	-	-
10/18	0.97	-	-	-	1.99	-	-	-	-	-
10/19	0.53	2.15	-	7.10	-	9.26	-	-	-	-
10/20	0.72	2.02	-	7.00	-	-	-	-	-	-
10/21	0.75	2.15	4.79	-	6.46	9.26	-	-	1.08	-
10/22	0.65	-	-	-	7.43	-	-	-	1.94	-
10/23	0.62	1.08	2.15	6.24	6.24	4.20	3.23	1.72	0.86	-
10/24	0.54	-	-	-	-	2.15	-	-	-	-
10/25	-	-	0.91	-	1.83	-	-	-	-	0.27
10/26	-	1.18	2.58	3.12	3.44	-	-	-	-	-
10/27	1.29	4.52	7.21	8.18	-	9.26	6.67	-	-	-
10/28	1.29	4.95	6.67	8.07	8.61	8.93	6.35	4.31	-	-
10/29	1.94	-	-	-	-	-	-	-	-	-
10/30	0.81	-	-	-	4.20	-	-	-	-	-
10/31	2.42	-	-	-	-	-	5.92	-	-	-
11/1/81	-	-	1.94	-	4.31	10.01	-	-	-	-
11/2	1.08	-	-	-	5.70	-	-	-	-	-
11/3	0.62	2.37	3.01	6.24	-	4.74	3.34	2.58	-	-
11/4	0.86	-	-	-	-	-	3.55	-	-	-
11/5	0.32	-	-	-	-	-	-	1.08	-	-
11/6	1.18	-	-	-	-	-	-	-	-	-
11/7	-	2.85	-	-	-	-	-	-	-	-
11/8	-	2.96	-	-	-	-	-	-	-	-
11/9	1.08	2.80	4.09	3.88	3.77	-	-	-	-	-

(Continued)

TABLE 7.7. (Continued)

11/10	-	-	-	-	-	-	-	-	-	-
11/11	1.18	-	-	-	-	-	-	-	-	-
11/12	2.26	-	-	-	-	-	-	-	-	-
11/13	2.37	-	-	-	-	-	-	-	-	-
11/14	1.08	2.37	-	-	6.24	-	4.74	-	-	-
11/15	1.08	3.12	-	-	-	-	-	-	-	-
11/16	-	-	-	-	-	-	-	-	-	-

Mean Illumination Values (Lumens·m^{-2}) x 10^4

	0800h	0900h	1000h	1100h	1200h	1300h	1400h	1500h	1600h	1700h
$\bar{x}$	1.06	2.68	3.97	6.47	5.76	7.40	6.35	2.42	2.49	1.40
s	0.55	1.07	1.79	1.72	2.42	2.88	2.57	1.40	1.36	1.60
n	29	14	14	10	15	9	11	4	7	3
95%CI	0.21	0.62	1.03	1.23	1.34	2.22	1.73	2.23	1.26	3.97

SECTION 8

QUANTIFICATION

Quantification was accomplished by High Pressure Liquid Chromatography (HPLC). Water and aufwuchs sample extracts were analyzed for anthracene and anthraquinone using a Varian Model 5000 LC, equipped with a 254 nm fixed wavelength UV detector, Varian 30 cm, MCH-10, C_{18} reverse phase column and a guard column of Whatman Co÷Pell ODS. Separations were made using a programmed gradient elution at 30°C and a flow rate of 1 $m\ell \cdot min^{-1}$. Elution solvent was 45% acetonitrile in water initially, programmed to 90% acetonitrile over 25 min, held at 90% acetonitrile for 5 min, with a recreation of initial conditions for 5 min before each injection. Injections were done automatically using a 25 $\mu\ell$ sample loop. Quantification was done by a Varian CDS 111-L integrator using the internal standard method. Chrysene was the internal standard of choice and was added to each sample extract in 2.0 $m\ell$ of acetonitrile just prior to each instrument run.

The recovery and precision for both matrices was determined by the fortified sample method (Table 8.1). Additionally, samples fortified with ^{14}C-anthracene were analyzed using HPLC and liquid scintillation counting (LSC) to verify techniques.

Background determinations for anthracene and anthraquinone in each matrix were made from control samples collected from a control channel receiving no anthracene input. Sets of treatment and control samples were analyzed for each sampling period. The detection limits for anthracene in

TABLE 8.1. RECOVERY AND PRECISION OF ANTHRACENE AND ANTHRAQUINONE FROM WATER AND AUFWUCHS MATRICES

Matrix	% Recover	
	Anthracene	Anthraquinone
Water	77 ± 5[a]	84 ± 5[a]
Aufwuchs	91 ± 3[b]	96 ± 2[b]

[a] $\bar{x} \pm 95\%CI$, n = 12

[b] $\bar{x} \pm 95\%CI$, n = 18

TABLE 8.2. LIMITS OF DETECTION FOR ANALYSIS OF ANTHRACENE AND ANTHRAQUINONE FROM WATER AND AUFWUCHS MATRICES

Matrix	Limit of Detection[a]	
	Anthracene	Anthraquinone
Water[b]	$6.9 \pm 1.0 \times 10^{-2}$	$36.6 \pm 5.3 \times 10^{-2}$
Aufwuchs	$3.0 \pm 0.39 \times 10^{-1}$[c]	1.7 ± 0.2[c]
	$1.3 \pm 0.3 \times 10^{-3}$[d]	$7.3 \pm 1.3 \times 10^{-3}$[d]

[a] $\bar{x} \pm 95\%CI$, n = 6

[b] $nmoles \cdot \ell^{-1}$

[c] $nmoles \cdot g^{-1}$

[d] $nmoles \cdot cm^{-2}$

water and anthraquinone in water and aufwuchs extracts (Table 8.2) were based on the HPLC detector baseline noise since there were no background peaks which eluted with the same retention time as the anthracene and anthraquinone standards. The baseline noise was monitored for 30 to 35 sec before each sample was analyzed. The detection limit was taken as 4x the mean noise level and was corrected for analytical recovery and sample size. The noise level was related to compound concentration by analyzing dilute standards so that detector noise, which is measured in μvolts, could be converted to compound concentration.

All laboratory procedures from extraction to analysis were conducted under gold fluorescent lights to minimize compound photodegradation.

SECTION 9

WATER DATA

Water samples of 500 mℓ were collected from all sampling stations at 1230h on days 9, 16, 23, 24, 30, and 37 and at 0800h on days 24 and 30. Additional duplicate water samples were collected hourly at one station per reach from dawn (0700h) to midday (1230h) on day 30. Water samples were collected from each sampling station (Fig. 4.2) in glass flasks, immediately placed in the dark and transported to the laboratory for extraction. Samples were extracted with 2 x 50 mℓ of pentane in glass separatory funnels. Extracts were combined, dried over anhydrous Na_2SO_4 and volume reduced to ~200 µℓ by rotary flash evaporation and evaporation under a nitrogen stream. A chrysene internal standard was added to each extract in 2 mℓ of acetonitrile. Analysis was by high pressure liquid chromatography (HPLC), as per section 8. Anthracene and anthraquinone recovery from spiked control samples was 77 $\pm$ 5% and 84 $\pm$ 5% ($\bar{x} \pm$ 95%CI, n = 12) respectively.

Tables 9.1 through 9.10 represent the water data summaries for the 1981 channels microcosms study. All anthracene and anthraquinone concentrations presented have been corrected for recovery and extraction efficiencies, and have been expressed on a molar (nmoles$\cdot\ell^{-1}$) basis (Tables 9.1, 9.2, and 9.3). Tables 9.4, 9.5 and 9.6 illustrate the response of anthracene and anthraquinone concentrations in the water to increasing levels of solar illumination. The illumination data which corresponds to this water data can be found in Table 7.7 (Section 7 this report). After

correcting all samples for recovery and efficiency, some loss of compound occurred between the input and discharge which was not accounted for by the sum of anthracene and anthraquinone (primary photoproduct). Tables 9.3 and 9.6 illustrate the changing mass balance accountability for stations moving downstream from input.

TABLE 9.1A. 1230h MEASURED ANTHRACENE WATER CONCENTRATIONS (nmoles·ℓ^{-1})[a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/19/81	82.1	86.9	64.5	40.3	36.7	28.7	20.3	16.9	14.7
10/26/81	87.6	79.8	60.4	36.1	39.4	27.8	39.3	46.4	21.8
11/2/81	77.8	71.1	71.2	40.4	36.8	32.2	24.4	22.1	19.8
11/3/81	84.4	78.2	56.9	43.6	23.4	22.5	23.1	20.6	22.4
11/9/81	83.9	105	77.9	49.0	43.5	43.0	33.6	33.9	27.5
$\bar{x}$	83.2	84.2	66.2	41.9	36.0	30.8	28.1	27.98	21.2
s	3.59	12.9	8.44	4.79	7.54	7.63	7.99	12.1	4.63
n	5	5	5	5	5	5	5	5	5
95%CI	4.46	16.0	10.5	5.95	9.37	9.48	9.92	15.03	5.75

TABLE 9.1B. 0800h MEASURED ANTHRACENE WATER CONCENTRATION (nmoles·ℓ^{-1})[a]

	R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
11/3/81	79.1	104.1	89.2	87.2	62.6	70.8	80.0	94.4	59.2
11/9/81 (0700h)	78.0			81.8					81.5
	86.6			102					80.7
11/9/81 (0800h)	84.1			86.5					72.7
	82.6			93.2					72.8
$\bar{x}$	82.1			90.1					73.4
s	3.55			7.77					8.96
n	5			5					5
95%CI	4.40			9.65					11.13

[a] Values are corrected for recovery and efficiency and are presented by reach and sampling station moving downstream from input.

TABLE 9.2A. 1230h MEASURED ANTHRAQUINONE WATER CONCENTRATION (nmoles·ℓ^{-1})[a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/19/81	1.59	6.27	4.20	15.7	18.1	19.8	18.9	17.6	16.2
10/26/81	2.27	3.95	5.56	7.85	10.3	8.92	16.0	20.4	10.4
11/2/81	1.66	3.92	8.83	11.4	13.6	14.0	15.4	14.7	12.7
11/3/81	2.75	4.70	4.96	11.2	9.03	11.0	14.3	14.7	16.3
11/9/81	1.14	2.76	4.93	11.2	12.7	15.1	16.6	17.4	16.1
$\bar{x}$	1.88	4.32	5.70	11.5	12.7	13.8	16.2	17.0	14.3
s	0.63	1.29	1.81	2.79	3.51	4.16	1.71	2.38	2.67
n	5	5	5	5	5	5	5	5	5
95%CI	0.78	1.60	2.25	3.46	4.35	5.17	2.13	2.95	3.32

TABLE 9.2B. 0800h MEASURED ANTHRAQUINONE WATER CONCENTRATION (nmoles·ℓ^{-1})[a]

	R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
11/3/81	ND	ND	ND	ND	ND	ND	0.34	ND	ND
11/9/81 (0700h)	ND			ND					ND
	ND			ND					ND
11/9/81 (0800h)	ND			2.10					2.07
	ND			2.10					1.90
$\bar{x}$	ND			2.10					1.99
s	-			-					-
n	-			2					2
95%CI	-			-					-

[a] Values are corrected from recovery and efficiency and are presented by reach and sampling station moving downstream from input.

TABLE 9.3A. 1230h ANTHRACENE PLUS ANTHRAQUINONE MASS BALANCE BASED ON nmoles·ℓ^{-1} [a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/19/81	83.7	93.2	68.7	56.0	54.8	48.5	39.2	34.5	30.9
10/26/81	89.9	83.7	66.0	44.0	49.7	36.7	55.3	66.8	32.2
11/2/81	79.5	75.0	80.1	51.8	50.4	46.1	39.8	36.8	32.5
11/3/81	87.1	82.9	61.9	54.8	32.4	33.5	37.4	35.3	38.8
11/9/81	85.0	107	82.9	60.2	56.2	58.2	50.2	51.3	43.6
$\bar{x}$	85.0	88.4	71.9	53.4	48.7	44.6	44.4	45.0	35.57
s	3.88	12.3	9.13	6.04	9.53	9.85	7.90	14.0	5.41
n	5	5	5	5	5	5	5	5	5
95%CI	4.82	15.22	11.33	7.50	11.83	12.23	9.81	17.4	6.73

TABLE 9.3B. 0800h ANTHRACENE PLUS ANTHRAQUINONE MASS BALANCE BASED ON nmoles·ℓ^{-1} [a]

	R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
11/3/81	79.1	104.0	89.2	87.2	62.6	70.8	80.3	94.4	59.2
11/9/81 (0700h)	78.0			81.8					81.5
	86.6			102					80.7
11/9/81 (0800h)	84.1			88.6					74.8
	82.6			95.4					74.7
$\bar{x}$	82.1			91.0					74.2
s	3.55			7.83					8.96
n	5			5					5
95%CI	4.40			9.72					11.1

[a] Data presented by reach and sampling station moving downstream from input.

TABLE 9.4. HOURLY MEASURED ANTHRACENE WATER CONCENTRATION (nmoles·ℓ^{-1}) FROM DAWN TO MIDDAY ON 11/9/81[a]

Time of Day	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
0700h	78.0			81.8					81.5
	86.6			102.9					80.7
0800h	84.1			86.5					72.7
	82.6			93.2					72.8
0900h	90.3			70.8					55.1
	85.5			72.0					56.4
1000h	93.1			55.7					46.0
	87.2			55.1					35.2
1230h	83.9	104.6	77.9	49.0	43.5	43.0	33.6	33.9	27.5

[a] Values are corrected for recovery and efficiency and are presented by reach and sampling station moving downstream from input.

TABLE 9.5. HOURLY MEASURED ANTHRAQUINONE CONCENTRATION (nmoles·ℓ^{-1}) FROM DAWN TO MIDDAY ON 11/9/81[a]

Time of Day	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
0700h	ND[b]			ND					
	ND			ND					ND
									ND
0800h	ND			2.1					
	ND			2.1					2.1
									1.9
0900h	ND			8.1					
	0.7			8.2					8.8
									9.0
1000h	0.7			12.3					
	1.1			12.0					17.9
									13.9
1230h	1.1	2.8	4.9	11.2	12.7	15.1	16.6	17.4	16.1

[a] Values are corrected for recovery and efficiency and are presented by reach and sampling station moving downstream from input.

[b] ND = not detected.

TABLE 9.6. HOURLY ANTHRACENE PLUS ANTHRAQUINONE MASS BALANCE FROM DAWN TO MIDDAY on 11/9/81 BASED ON nmoles·ℓ^{-1} [a]

Time of Day	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
0700h	78.0			81.8					81.5
	86.6			102.9					80.7
0800h	84.1			88.6					74.8
	82.6			95.3					74.7
0900h	90.3			78.9					63.9
	86.2			80.2					65.4
1000h	93.8			68.0					63.9
	88.3			67.1					49.1
1230h	85.0	107.4	82.8	60.2	56.2	58.1	50.2	51.3	43.6

[a] Data presented by reach and sampling station moving downstream from input.

SECTION 10

AUFWUCHS DATA

Aufwuchs samples were collected at 0800 on days 4, 11, 18, 25, 32 and 39, from three sampling stations within reaches 1, 3 and 5 (Figure 4.2). Aufwuchs samples were taken by scraping a constant surface area of 64.8 cm^2 from the channel walls. The ability to assure a constant sampling surface area was accomplished using a plexiglass chamber (12.7 cm x 5.1 cm) to enclose the aufwuchs surface to be sampled. Two separate aufwuchs samples were collected from each station, one each from the shaded and sunlit walls of the experimental channels. Samples were removed in a 200 mℓ suspension with water from the channel, placed into glass beakers and kept in the dark until extracted. Prior to extraction samples were blended for 10 sec, filtered through Whatman #42 filter paper and wet weight determined. Samples were then subsampled for extraction and determination of dry weight, ash weight and ash-free dry weight (Standard Methods, 1976). Samples were extracted by homogenizing in 2 x 12 mℓ ethylacetate-acetone (4:1, V:V) and 2 x 12 mℓ cyclohexane in a Ten Broeck glass tissue homogenizer. Extracts were combined and stored 12h at -20°C after which extracts were dried over Na_2SO_4, volume reduced, and chrysene internal standard was added as previously described for water samples (Section 9). Analysis was by HPLC (Section 8) and recovery of anthracene and anthraquinone from spiked control samples was 91 $\pm$ 3% and 96 $\pm$ 2% ($\bar{x} \pm$ 95%CI, n = 18) respectively.

All anthracene concentrations reported in Tables 10.1 through 10.4 have been corrected for recovery and efficiency. Anthracene concentration in the aufwuchs has been expressed on both a surface area sampled (cm^2) (Table 10.1) and dry weight (g) (Table 10.2) basis. Data from the dry weight Table 10.3 can be converted to wet weight or ash-free dry weight by using the dry to wet weight and dry to ash-free weight ratios presented in Table 10.4 and 10.5.

Anthraquinone concentrations in aufwuchs were below the anthraquinone detection limits of our analytical procedure. This suggests that the aufwuchs community did not metabolize anthracene to anthraquinone nor did it accumulate anthraquinone from the water. This finding has been supported by a laboratory study using aufwuchs material from the channels and ^{14}C labeled anthracene, in which no degradation of ^{14}C-anthracene by aufwuchs was detected using HPLC and liquid scintilation techniques.

A bioconcentration factor (BCF) for aufwuchs was calculated (Equation 10.1) using anthracene concentrations measured for aufwuchs (Table 10.2) and the 24h weighted anthracene water concentration for each sampling date.

$$BCF = \frac{C}{C_w} \qquad (10.1)$$

where

C = concentration in the aufwuchs, $ng \cdot g^{-1}$ dry wt.

C_w = weighted anthracene concentration in the water, $ng \cdot ml^{-1}$

TABLE 10.1. 0800h MEAN AUFWUCHS ANTHRACENE CONCENTRATION nmoles·cm^{-2} (SURFACE AREA SAMPLED)[a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/14/81	0.87	0.60	0.30	0.50	0.34	0.32	0.14	0.18	0.21
	1.5	1.00	0.18	0.44	0.44	0.46	0.29	0.26	-
10/21/81	0.8	0.46	0.49	0.34	0.30	0.30	0.25	0.30	0.33
	1.4	0.94	0.48	0.35	0.57	0.35	0.25	0.36	0.35
10/28/81	1.5	0.94	0.68	0.36	0.26	0.39	0.23	0.26	0.22
	1.3	1.1	1.00	0.50	0.61	0.48	0.39	0.43	0.24
11/4/81	1.2	0.7	-	0.24	0.26	0.25	0.14	0.25	0.17
	0.91	0.97	0.63	0.46	0.34	0.22	0.31	0.28	0.22
11/11/81	1.6	0.81	0.29	0.48	0.46	0.43	0.36	0.35	0.40
	1.3	1.1		0.67	0.81	0.44	0.40	0.42	0.28
$\bar{x}$	1.2	0.86	0.51	0.43	0.44	0.36	0.28	0.31	0.27
s	0.28	0.21	0.26	0.12	0.18	0.09	0.09	0.08	0.08
n	10	10	8	10	10	10	10	10	9
95% CI	0.20	0.15	0.22	0.09	0.13	0.06	0.07	0.06	0.06

[a] Values are corrected for recovery and efficiency and are presented by reach and sampling station moving downstream from input.

TABLE 10.2. 0800h MEAN AUFWUCHS ANTHRACENE CONCENTRATION nmoles·g^{-1} dry wt.[a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/14/81	83.3	88.2	49.0	110	133	108	54.9	137	52.9
	222	145	215	97.1	93.8	52.4	81.4	88.0	-
10/21/81	80.1	55.9	88.7	72.4	86.6	68.2	72.3	58.5	105
	111	78.2	62.6	19.6	150	90.4	113	119	140
10/28/81	128	137	51.8	75.4	77.2	123	70.0	95.6	85.4
	120	84.2	95.0	86.0	122	131	89.2	127	86.1
11/4/81	119	81.5	-	67.0	66.5	70.6	35.7	80.3	91.6
	85.5	85.4	73.1	83.1	62.1	70.6	81.4	75.7	61.7
11/11/81	104	123	58.2	99.3	116	165	109	124	121
	118	83.1	-	119	182	105	117	120	122
$\bar{x}$	117	96.2	86.7	82.9	109	98.4	82.4	102	96.2
s	40.6	28.7	54.4	27.8	38.8	34.7	26.0	26.3	28.7
n	10	10	8	10	10	10	10	10	9
95% CI	29.1	20.5	45.5	19.9	27.8	24.9	18.6	18.8	22.0

[a] Values are corrected for recovery and efficiency and are presented by reach and sampling station moving downstream from input.

TABLE 10.3. AUFWUCHS MEAN BIOMASS mg dry wt·cm^2 (SURFACE AREA SAMPLED)[a]

Experimental Date	Station R1#1	R1#2	R1#3	R3#1	R3#2	R3#3	R5#1	R5#2	R5#3
10/14/81	10.4	6.75	6.11	4.54	2.55	2.91	2.48	1.31	4.00
	6.84	6.97	8.52	4.55	4.72	8.73	3.55	2.98	2.30
10/21/81	10.0	8.24	5.52	4.62	3.44	4.33	3.41	5.15	3.12
	12.2	12.1	7.61	17.9	3.78	3.88	2.20	3.03	2.50
10/28/81	11.6	6.86	13.2	4.77	3.36	3.17	3.28	2.71	2.59
	11.0	12.9	10.5	5.76	4.99	3.63	4.34	3.38	2.84
11/4/81	10.5	8.48	5.90	3.62	3.95	3.57	3.92	3.16	1.91
	10.6	11.4	8.61	5.51	5.43	3.09	3.82	3.74	3.55
11/11/81	15.5	6.65	4.92	4.83	4.01	2.53	3.33	2.82	3.32
	10.7	12.9	7.44	5.68	4.47	4.23	3.41	3.50	2.27
$\bar{x}$	10.9	9.32	7.83	6.18	4.07	4.01	3.37	3.18	2.84
s	2.14	2.68	2.53	4.17	0.86	1.76	0.64	0.96	0.65
n	10	10	10	10	10	10	10	10	10
95% CI	1.53	1.92	1.81	2.98	0.61	1.26	0.46	0.69	0.46

[a] Values are presented by reach and sampling station moving downstream from input.

TABLE 10.4. AUFWUCHS DRY TO WET WEIGHT RATIO

Sampling Date	Mean Dry to Wet Weight Ratio by Channel Reach		
	Reach #1	Reach #3	Reach #5
10/14/81	0.050 ± 0.052[a]	0.105 ± 0.029	0.125 ± 0.036
10/21/81	0.068 ± 0.017	0.101 ± 0.055	0.112 ± 0.062
10/28/81	0.080 ± 0.053	0.065 ± 0.006	0.081 ± 0.016
11/4/81	0.070 ± 0.029	0.117 ± 0.019	0.118 ± 0.025
11/11/81	0.069 ± 0.028	0.080 ± 0.009	0.081 ± 0.008
Overall Mean by Reach	0.067 ± 0.011[b]	0.094 ± 0.012	0.103 ± 0.013
Overall Mean for Channel		0.088 ± 0.008[c]	

[a] $\bar{x}$ ± 95% CI, n = 6

[b] $\bar{x}$ ± 95% CI, n = 30

[c] $\bar{x}$ ± 95% CI, n = 90

TABLE 10.5. AUFWUCHS ASH-FREE TO DRY WEIGHT RATIO

Sampling Date	Mean Ash-Free to Dry Weight Ratio by Channel Reach		
	Reach #1	Reach #3	Reach #5
10/14/81	0.805 ± 0.054[a]	0.726 ± 0.245	0.763 ± 0.168
10/21/81	0.791 ± 0.103	0.719 ± 0.271	0.861 ± 0.016
10/28/81	0.715 ± 0.216	0.862 ± 0.043	0.796 ± 0.062
11/4/81	0.790 ± 0.038	0.831 ± 0.034	0.852 ± 0.051
11/11/81	0.800 ± 0.123	0.850 ± 0.028	0.846 ± 0.033
Overall Mean by Reach	0.780 ± 0.043[b]	0.797 ± 0.060	0.826 ± 0.028
Overall Mean for Channel		0.801 ± 0.026[c]	

[a] $\bar{x}$ ± 95% CI, n = 6

[b] $\bar{x}$ ± 95% CI, n = 30

[c] $\bar{x}$ ± 95% CI, n = 90

TABLE 10.6. AUFWUCHS BIOCONCENTRATION FACTOR (BCF)

Sampling Date	Mean BCF by Channel Reach		
	Reach #1	Reach #3	Reach #5
10/14/81	1620 ± 562[a]	1370 ± 534	1150 ± 1140
10/21/81	959 ± 437	1120 ± 1250	1490 ± 714
10/28/81	1250 ± 680	1440 ± 874	1280 ± 501
11/4/81	1080 ± 358	1020 ± 130	1070 ± 413
11/11/81	973 ± 727	1590 ± 645	1510 ± 181
Overall Mean by Reach	1180 ± 228[b]	1310 ± 190	1300 ± 164
Overall Mean for Channel		1260 ± 96[c]	

[a] $\bar{x}$ ± 95% CI, n = 3

[b] $\bar{x}$ ± 95% CI, n = 15

[c] $\bar{x}$ ± 95% CI, n = 45

A weighted anthracene water concentration was determined by first calculating the total anthracene exposure for both the daytime (light period) and nighttime (dark period) periods. Anthracene exposures for daytime and nighttime were calculated using the 1230h measured anthracene water concentration (Table 9.1A) and the calculated nominal anthracene input concentration derived from assays of the anthracene stock solution (Table 5.2), for the 24h period prior to aufwuchs sample collection, and multiplying by an appropriate weighting factor. The reason for using the nominal anthracene input calculated for the 24h period preceeding aufwuchs collection was that aufwuchs samples were taken at 0800h approximately the same time anthracene input stock solutions were changed. Thus the aufwuchs samples for a given collection date had actually received the majority of their anthracene exposure from the preceeding day's anthracene stock solution and its corresponding dilution factors.

The daytime weighting factor was derived by plotting the mean daily solar irradiance profile for the experimental period, then integrating the area of total solar irradiance under the curve and dividing by the mean solar irradiance rate at 1230h when water samples were collected. This gave an estimate of the anthracene exposure period based on the daily maximum solar irradiance rate and its corresponding anthracene water concentration measured at 1230h. The daytime weighting factor calculated by this method for the experimental period was 5.91h. This weighting factor was multiplyed times the 1230h anthracene water concentration measured at each sampling station to calculate the daytime anthracene exposure for each station.

The nighttime weighting factor was calculated by difference. The daytime weighting factor (5.91h) was substracted from 24, the number of

hours in a day. The resulting nighttime weighting factor was 18.09h. A nighttime anthracene exposure was then calculated by multiplying the nominal anthracene input by the nighttime weighting factor.

Once both the daytime and nighttime anthracene exposures were calculated, the 24h weighted anthracene water concentration was determined by summing the total daytime and nighttime anthracene exposures and dividing by 24h. The resulting weighted anthracene water concentration has units of $\mu g \cdot \ell^{-1}$. This procedure was applied for all sampling stations in reaches 1, 3, and 5 and thus allowed the calculation of an appropriate anthracene water concentration for use with specific aufwuchs samples. The results of the BCF calculations are summarized in Table 10.6.

REFERENCES

Andelman, J. B. and J. E. Snodgrass. 1974. Incidence and significance of polynuclear aromatic hydrocarbons in the water environment. CRC Critical Reviews in Environmental Control 4:69-83.

Archer, S. R., T. R. Blackwood and G. E. Wilkins. 1979. Status Assessment of Toxic Chemicals: Polynuclear Aromatic Hydrocarbons, EPA-600/2-79-210L, U. S. Environmental Protection Agency, Cincinnati, OH. 33 pp.

Ausmus, B. S., G. K. Eddlemon, S. J. Draggan, J. M. Giddings, D. R. Jackson, R. J. Luxmoore, E. G. O'Neill, R. V. O'Neill, Monte Ross-Todd and P. Van Voris. 1980. Microcosms as Potential Screening Tools for Evaluating Transport and Effects of Toxic Substances. W. F. Harris (ed.). ORNL/EPA 4, EPA-600/3-80-042, U. S. Environmental Protection Agency, Athens, Ga. 379 pp.

Baughman, G. L. and R. R. Lassiter. 1978. Prediction of environmental pollutant concentration. pp. 35-54. In: Estimating the Hazard of Chemical Substances to Aquatic Life. J. Cairns, Jr., K. L. Dickson and A. W. Maki, (eds.). American Society for Testing Materials, ASTM STP 657.

Black, G. R., ed. 1965. Methods of Soil Analysis - Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. American Society of Agronomy, Inc. Publisher, Madison, WIS. 770 pg.

Bowling, J. W., J. P. Giesy, H. J. Kania and R. L. Knight. 1980. Large-scale microcosms for assessing fates and effects of trace contaminants. pp. 224-247. In: Microcosms in Ecological Research. J. P. Giesy (ed.). U. S. Department of Energy Technical Information Center, Oak Ridge, TN.

Burns, L. A., D. M. Cline, R. R. Lassiter. 1982. Exposure Analysis Modeling System (EXAMS): User Manual and System Documentation. EPA-600/3-82-023, U. S. Environmental Protection Agency, Athens, Georgia.

Clar, E. 1964. Polycyclic Hydrocarbons. Academic Press, London.

Crawford, D. J. and R. W. Leggett. 1980. Assessing the risk of exposure to radioactivity. Amer. Sci. 68:524-636.

Deichmann, W. B. and H. W. Gerarde. 1969. Toxicology of Drugs and Chemicals. Academic Press, New York. 805 pp.

Duthie, J. R. 1977. The importance of sequential assessment in test programs for estimating hazard to aquatic life. pp. 17-35. In: Aquatic Toxicology and Hazard Evaluation, F. L. Mayer and J. L. Hamelink (eds.). American Society for Testing and Materials, ASTM STP 634 pp.

Giesy, J. P., S. M. Bartell, P. F. Landrum, G. J. Leversee, J. W. Bowling, M. G. Bruno, T. E. Fannin, S. Gerould, J. D. Haddock, K. LaGory, J. T. Oris, and A. Spacie. 1983. Fates and Biological Effects of Polycyclic Aromatic Hydrocarbons in Aquatic Systems. EPA 600/3-83-053, U. S. Environmental Protection Agency, Athens, Ga.

Greenberg, A. E., J. J. Connors and D. Jenkins. eds. 1980. Standard Methods for the Examination of Water and Wastewater, 15th edition. American Public Health Association, Washington, DC. 1134 pp.

Guerin, M. 1975. Coal Technology Progress Report. ORNL/TM-4850, Oak Ridge National Laboratory.

Handbook of Chemistry and Physics. 1980-1981. 61st ed. R. C. Weast (ed.). CRC Press, Inc., Boca Raton, Fla.

Herbes, S. E., G. R. Southworth, D. L. Shaeffer, W. H. Griest, M. P. Maskarinec. 1980. Critical pathways of polycycli aromatic hydrocarbons in aquatic environments. pp. 113-128. In: Scientific Basis of Toxicity Assessment. H. Witschi (ed.). Elsevier/North-Holland Biomedical Press. New York, NY.

Hill, J. 1979. Mathematical modeling of pesticides in the environment: current and future developments. J. Environ. Systems 9:99-106.

Jordan, T. E. 1954. Vapor pressures of organic compounds. Interscience Publishers, Inc., New York.

Karickhoff, S. W., D. S. Brown and T. A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res. 13:241-248.

Kenaga, E. E. and C. A. I. Goring. 1980. Relationship between water solubility, soil sorption, octanol-water partitioning, and concentration of chemicals in biota. pp. 78-115. In: Aquatic Toxicology. J. G. Eaton, P. R. Parrish, and A. C. Hendricks (eds.), American Society for Testing and Materials, ASTM 707.

Knight, R. L. 1980. Energy Basis of Control in Aquatic Ecosystems. Ph.D. Thesis. University of Florida, Gainesville, Florida. 200 pp.

Knapp, C. L., T. L. Stoffel and S. D. Whitaker. 1980. Insolation Data Manual: long-term monthly averages of solar radiation, temperature, degree-days and global $\bar{K}_T$ for 248 national weather service stations. SERI/SP-755-789, Solar Energy Research Institute, Golden, Colorado.

Leversee, G. J., P. F. Landrum, J. P. Giesy and T. Fannin. 1983. Effect of humics on polycyclic aromatic hydrocarbons: accumulation by Daphnia magna and coprecipitation at estuarine salinities. Can. J. Fish. Aq. Sci. (In press).

National Academy of Sciences (USA). 1972. Particulate Polycyclic Organic Matter. Washington, D.C. 361 pp.

Neff, J. M. 1978. Polycyclic aromatic hydrocarbons in the aquatic environment and cancer risk to aquatic organisms and man. In: Symposium: Carcinogenic Polynuclear Aromatic Hydrocarbons in the Marine Environment. N. L. Richards and B. L. Jackson (eds.), EPA-600/9-82-013, U. S. Environmental Protection Agency, Pensacola, Florida.

Page, A. L. ed. 1982. Methods of Soil Analysis - Part 2 Chemical and Microbiological Properties Second Edition. American Society of Agronomy, Inc. Soil Science Society of America, Inc. Publisher, Madison, WIS.

Roubal, W. T., T. K. Collier, and D. C. Malins. 1977. Accumulation and metabolism of carbon-14 labeled benzene, naphthalene, and anthracene by young coho salmon (Oncorhynchus kisutch). Arch. Environ. Contam. Toxicol. 5:513-529.

Southworth, G. R. 1979a. The role of volatilization in removing polycyclic aromatic hydrocarbons from aquatic environments. Bull. Environ. Contam. Toxicol. 21:507-514.

Southworth, G. R. 1979b. Transport and transformations of anthracene in natural waters. pp. 359-380. In: Aquatic Toxicology. L. L. Marking and R. A. Kimerle (eds.), American Society for Testing and Materials, ASTM STP 667.

Spacie, A., P. F. Landrum, and G. J. Leversee. 1983. Uptake, depuration and biotransformation of anthracene and benzo(a)pyrene in bluegill sunfish. Ecotox. Environ. Safety (In Press).

Standard Methods for the Examination of Water and Wastewater. 1975. 14th ed. M. C. Rand, A. E. Greenberg and M. J. Taras (eds.). American Public Health Association, Washington, D.C. 1193 pp.

Sunshine, I. (ed.). 1969. CRC Handbook of Analytical Toxicology. The Chemical Rubber Co., Cleveland, OH. 1081 pp.

Zepp, R. G. 1979. Assessing the photochemistry of organic pollutants in aquatic environments. In: Dynamics, Exposure, and Hazard Assessment of Toxic Chemicals. R. Hague (ed.), Ann Arbor Science Publishers, Ann Arbor, Mich.

Zepp, R. G. and P. F. Schlotzhauer. 1979. Photoreactivity of selected aromatic hydrocarbons in water. pp. 141-158. In: Polynuclear Aromatic Hydrocarbons: Third International Symposium on Chemistry and Biology - Carcinogensis and Mutagenesis. P. W. Jones and P. Leber (eds.). Ann Arbor Science, Ann Arbor, Mich.